K-Ar AGES OF MUSCOVITE AND BIOTITE FROM THE BLUE RIDGE PROVINCE, NORTHERN VIRGINIA

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by

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Introduction

The Paleozoic metamorphic history of the Appalachian orogen continues to be a matter of considerable controversy, with much debate centering around work done in the area studied for this report. Post Precambrian K-Ar mineral ages in the Appalachians range from approximately 450 to 250 million years and are generally distributed with the older ages in the west and progressively younger ages toward the southeast. These ages define geochronological provinces which trend northeast along the length of the Appalachian system. Early workers believed these provinces represented the effects of several distinct Paleozoic metamorphic episodes (Long and others, 1959; Clark and Kulp, 1968; Carpenter, 1970) including an early Paleozoic Taconic Orogeny (approximately 480 m.y.a.), a middle Paleozoic Acadian Orogeny (approximately 360 m.y.a.), and a late Paleozoic Appalachian Orogeny(300 m.y.a.).

Recent isotopic dating studies suggest that the K-Ar ages are cooling, gas retention dates which post-date regional metamorphism and that the distribution of dates reflects rates of cooling and/or uplift rather than separate orogenic events (Hadley, 1964; Rodgers, 1971; Dallmeyer, 1978).

In the Reading Prong there is no history of Paleozoic overprinting in the basement complex west of the Hudson River. East of the river, however, the Precambrian rocks show retrogressive alteration. K-Ar and $^{40}Ar/^{39}Ar$ mineral dates reflect this with a general west to east decrease in age (Dallmeyer, Sutter and Baker, 1975).

The Grenville terrane of the southern Blue Ridge, North Carolina, on the other hand, clearly shows retrogressive effects of Paleozoic metamorphism. $^{40}Ar/^{39}Ar$ results reported by Dallmeyer (1975) for this area are similar to those of the Reading Prong. Dallmeyer (1975) and Dallmeyer, Sutter and Baker (1975) demonstrated that the distribution of dates was due to cooling and uplift following early Paleozoic metamorphism.

This project was initiated as a part of the ongoing study of Paleozoic metamorphic and tectonic history of the Appalachian orogen. To compliment current studies of the Reading Prong, southern Blue Ridge and Piedmont provinces, data was obtained from the Northern Blue Ridge province.

The primary objective of this study is to determine isotopic cooling dates for minerals from the Blue Ridge province and Piedmont province in northern Virginia and relate these dates to regional metamorphism in this portion of the Appalachian orogen.

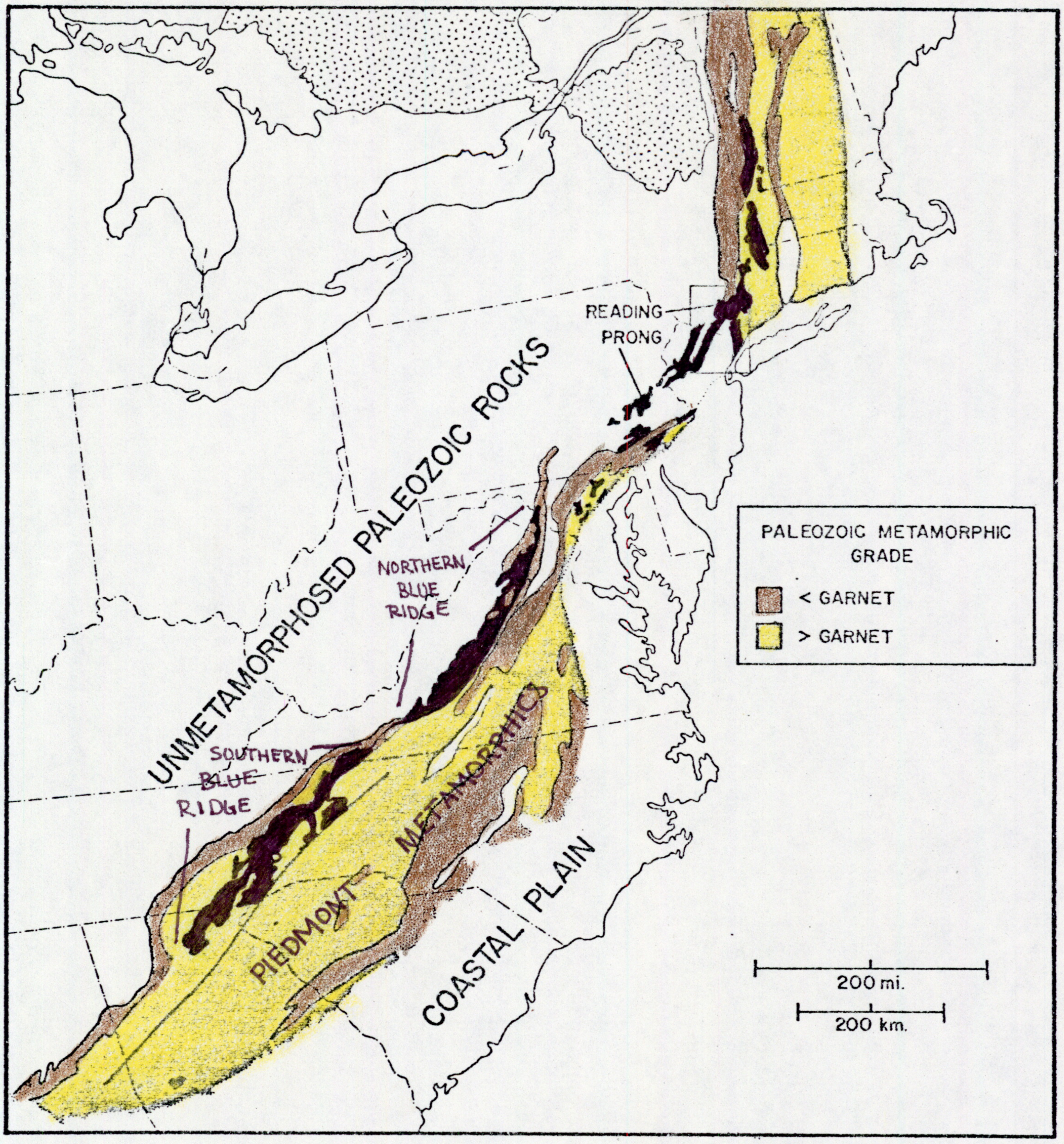

Figure 1. General map of the Appalachian Mountains, eastern United States, showing physiographic provinces and the relationship of metamorphic grade to the Grenville basement complex (black). Adapted from Morgan (1972).

Geological Setting of the Blue Ridge Anticlinorium, Northern Virginia

The Appalachian Mountains in Virginia and Maryland are folded into a broad anticlinorium characterized by a central core of older Precambrian granitic rocks that are flanked to the north, east and west by Precambrian meta-sedimentary and meta-volcanic rocks and overlying Paleozoic rocks (figure 2).

To the north, in Maryland, the Blue Ridge physiographic province coincides with the anticlinorium as it plunges gently northeastward under younger Precambrian stratified units. In Virginia, only the western limb and western portion of the core are included in the Blue Ridge province. The eastern limb of the anticlinorium is considered a part of the Piedmont province (from Espenshade, 1970). To the west, the Blue Ridge is bordered by Paleozoic rocks of the Valley and Ridge province. This study is mainly concerned with units in the core and on the eastern limb of the Blue Ridge anticlinorium which, for the purpose of this paper, will be considered as part of the Blue Ridge province.

Stratigraphy

The lower Precambrian granitic basement complex of the Blue Ridge anticlinorium is composed of a variety of plutonic granitic gneisses and intrusives which range in composition from biotite granite to anorthosite. All but a very few of the westernmost basement rocks show retrogressive effects of Paleozoic greenschist

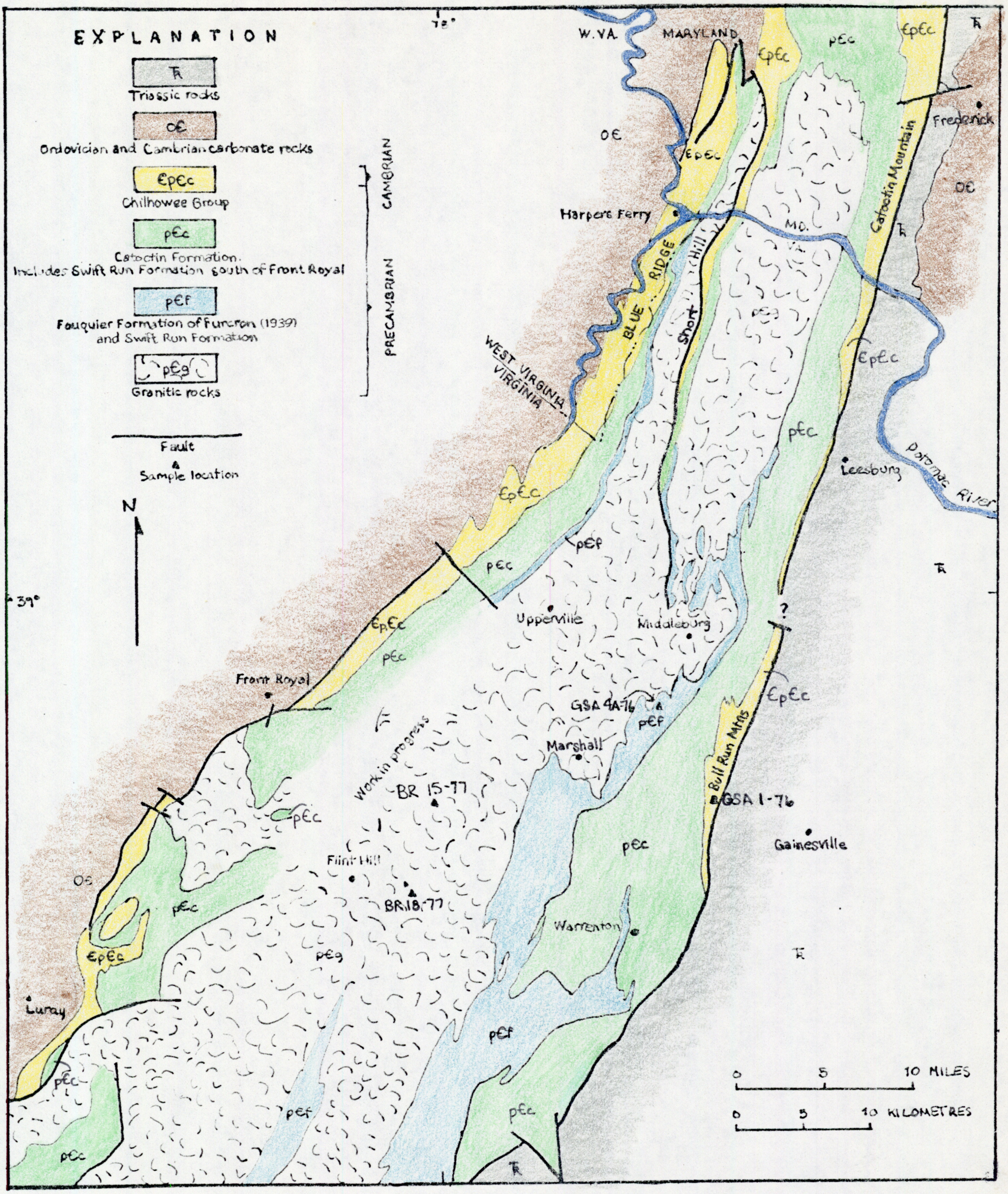

Figure 2. Generalized geologic map of the northern part of the Blue Ridge anticlinorium showing sample locations. Adapted from Espenshade and Clarke (1976).

metamorphism (Tilton, et. al., 1960) and most are strongly foliated to charnockitic in nature (Espenshade, 1970, p. 208).

According to Espenshade (1976), the Flint Hill Gneiss, a layered biotite gneiss, is the oldest unit. It is cut by strongly foliated biotite, quartz, feldspar, granitic gneiss of the Marshall Formation (Virginia Div. of Mineral Resources, 1963) as well as blue quartz pods and veins. Granitic dikes cut both the Flint Hill Gneiss and the Marshall Formation. The non-foliated granitic Robertson River Formation (Allen, 1963) also intrudes the Flint Hill Gneiss.

Some workers have proposed granitization of sedimentary rocks as the origin of much of the basement complex (Allen, 1963, p. 70-71; Brown, 1958, p. 17; Bloomer and Werner, 1955, p. 581-582). However, studies of the heavy mineral suites in the overlying Fauquier Formation of Furcron (1939) containing magnetite, zircon, apatite and ilmenite indicate an igneous origin for the granitic basement complex (Espenshade and Clarke, 1976).

Isotopic dates from the granitic basement rocks in the Blue Ridge in northern Virginia indicate garnet-kyanite grade metamorphism of the gneisses approximately 1,000 to 1,100 million years ago (Tilton, et. al., 1960; Davis, et. al., 1962; John Sutter, personal communication).

Resting unconformably on the granitic basement complex is the Precambrian meta-sedimentary unit named the Fauquier Formation by Furcron (1939). It is composed of meta-conglomerate, meta-arkose, meta-siltstone, slate and marble. Several depositional environments are suggested by such varied lithology including fluvial conditions for the cross-bedded arkose and conglomerate and quiet water conditions for the limestone and shale deposition (Espenshade and Clarke, 1976).

Rocks similar to those of the Fauquier Formation of Furcron (1939) and found on the east limb of the anticlinorium have previously been called the Swift Run Formation (Parker, 1968). This name is currently used for pre-Catoctin sediments on the west limb and nose of the anticlinorium. Furcron (1939) proposed that the Fauquier Formation be divided into the (lower) Bunker Hill Formation and upper Fauquier Formation, both being included in the Lynchburg Group which is the name used for rock units in central and southern Virginia. Espenshade and Clarke (1976) have proposed that the Fauquier Formation (Furcron, 1939) includes all pre-Catoctin meta-sedimentary units on the east limb of the anticlinorium.

The Precambrian Catoctin Formation is a narrow belt of meta-volcanic and meta-sedimentary units found on both limbs and the nose of the Blue Ridge anticlinorium. It has a maximum thickness of 550 meters and lies conformably on the Fauquier Formation (Furcron, 1939) except to the north in Maryland, where it lies unconformably on the granitic basement complex. The Cotoctin Formation consists of a series of basalt flows, metamorphosed to greenschist facies during Paleozoic deformation. The basalt flows are interlayered with thin beds of quartzite and mica schist on the northwest and east side of the anticlinorium. Meta-rhyolite is found to the north in Maryland and Pennsylvania (Jonas and Stose, 1933; Stose and

Stose, 1946) and has also been found on the west limb by Gathright and Nystrom (1974). Meta-diabase dikes which intrude the granitic basement rocks throughout the northern Blue Ridge are said to be feeder dikes to the Catoctin flows (Espenshade and Clarke, 1976).

Discordant U-Pb ages of approximately 820 million years from the meta-rhyolites have been proposed by Rankin and others (1969) as the age of the Catoctin flows. This would leave a 200 million year time span before the deposition of the Chilhowee Group (Espenshade and Clarke, 1976) of uppermost Precambrian and lower Cambrian age. The Chilhowee Group is found on both limbs of the anticlinorium. An unconformity below the rocks of this group has been reported in Maryland (Stose and Stose, 1946; Wickham, 1972), but is not field evident in central Virginia (Bloomer and Werner, 1955; Werner, 1966). The Chilhowee Group includes the Loudon, Weverton, Harpers and Antietam Formations and consists mainly of up to 1500 meters of quartzite, sandstone, siltstone, shale and phyllite (Wickham, 1972; Espenshade, 1970).

Above the Chilhowee Group to the east lie rocks of the Triassic basin. To the west of the anticlinorium lie Ordovician and Cambrian carbonates.

The K-Ar Method and Analytical Techniques

Samples collected were selected for K-Ar analysis on the basis of mineral composition and grain size (each of the samples studied contained 5 to 10% mica). Whole rock samples were systematically crushed and seived to maximize the 100-140 mesh fraction, then washed in acetone, alcohol and distilled water. Biotite was separated by heavy liquid and isodynamic magnetic methods to >99% purity. Approximately 0.05g. aliquants were prepared for potassium determination using the method described by Cooper (1963) and analyzed on a Zeiss PF-5 single channel Flame Photometer.

A second aliquant of each sample was packed in a high-purity aluminum capsule and loaded into a sample bottle. Each sample was fused and gases were extracted and purified according to the method described by Dalrymple and Lanphere (1969, p. 62-65). The isotopic composition of Ar released from the sample as well as the ^{38}Ar tracer was determined with a Nuclide Mass Spectrometer (6" radius, 60° sector). Results from the analyses are found in Table I.

Petrography

Sample GSA 1-76 is a quartz-mica schist from the Weverton Formation of the Chilhowee Group (see figure 2 for location). The principal mineral constituent is quartz which forms a tight polygonal mozaic 1-5 mm. thick between thin micaceous layers less than 1 mm. thick (figure 3A). At least two micas are present: subhedral parallel oriented muscovites and sericite as well as rust brown subhedral laths of biotite. Very little chloritization of the micas is present. Accessory minerals include well-rounded detrital zircon, magnetite and tourmaline showing well-rounded detrital cores and subhedral to euhedral overgrowth. The large zircon and tourmaline grains form minute augen with some chloritization around tourmaline grain boundaries (see figure 3A). Smaller tourmaline grains show good tourmaline cross section and all show zoning.

GSA 4A-76 is a phyllite from the Fauquier Formation of Furcron (1939) (see figure 2 for location). The main constituent is sericitic white mica (60%). Subhedral green and brown biotite laths have been formed at the expense of white micas and iron oxides. Two foliations appear in thin section (figure 3B) with stringlets of partly recrystallized relict clays throughout. Accessory minerals make up less than 2% of the rock and include magnetite and chlorite.

BR 15-77 and BR 18-77 are very similar petrographically and will be treated together in this description. The Flint Hill Gneiss at both of these localities is a coarse grained quartz monzonite gneiss with microcline, quartz and andesine-oligoclase being major constituents. Biotite makes up 8% of the rock, muscovite 3% and zircon, sphene, apatite, magnetite, ilmenite and chlorite combined comprise 5% of the total. Some, but not all, of the biotites are intergrown with fine needles of rutile (as seen in figure 3C). The rocks are irregularly foliated and almost charnokitic in nature, with the leucocratic layers containing blue quartz, microcline and plagioclase, being discontinuous and characterized by augen and pod shaped bodies. Alteration of feldspars to sericite creates birdseye extinction, and sericite and chlorite are found along grain boundaries, especially in the ferromagnesian layers (figure 3D).

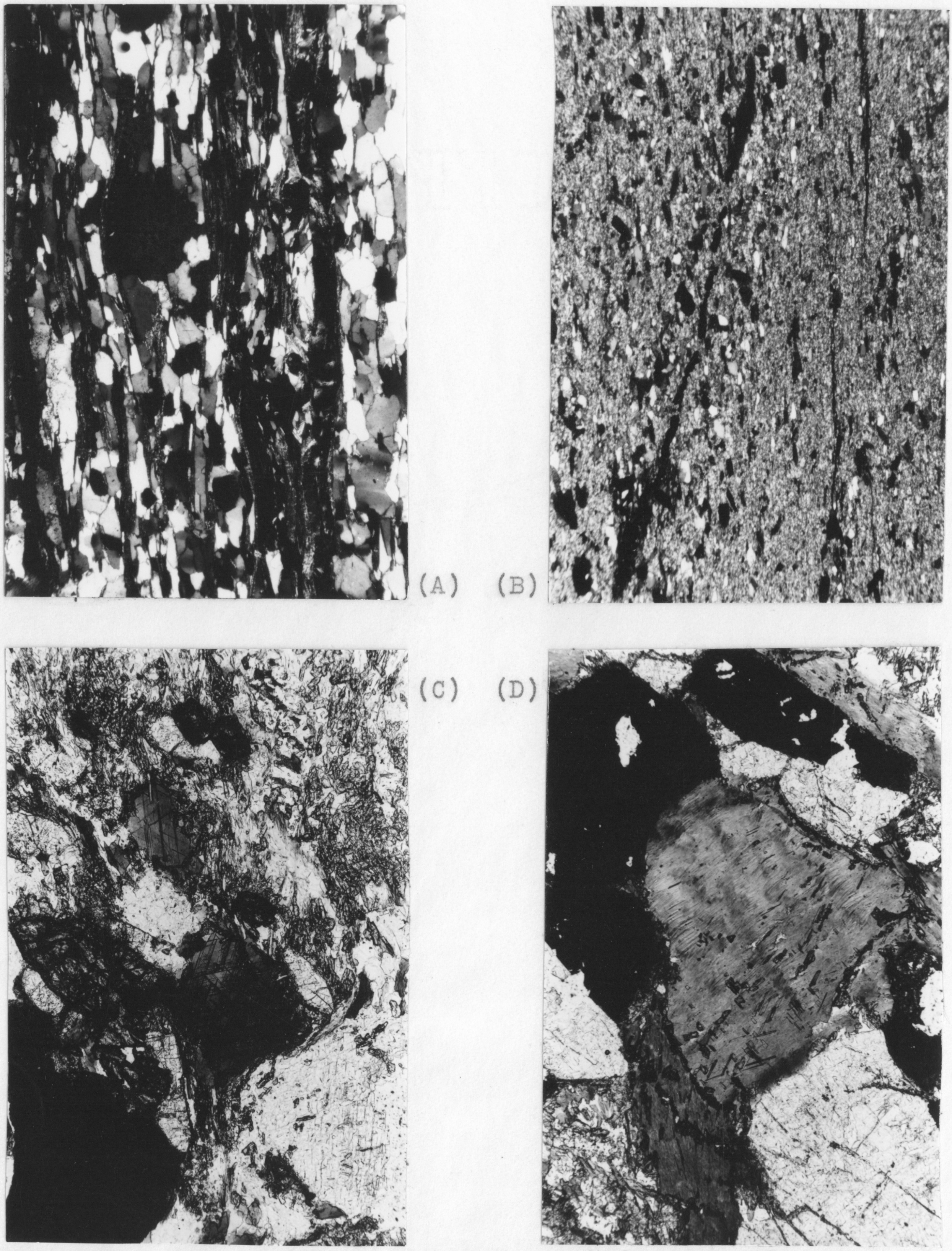

Figure 3. Thin sections of samples: (A) GSA 1-76, schistosity (magnified 40x); (B) GSA 4a-76, pods of relict clays (40x); (C) BR 18-77, rutile needles in biotite (100x); (D) BR 18-77, feldspar alteration (100x).

Table I

K-Ar analytical data for biotite and muscovite from Precambrian rocks of the Blue Ridge anticlinorium, Northern Virginia

Sample number	K (wt, %)[2]	Moles $^{40}Ar^{*}$/gm.	Radiogenic ^{40}Ar (%)	K-Ar age (m.y.)[3]
		Biotite		
BR 18-77	6.541	5.044×10^{-9}	96.5	397.6± 4.6
BR 15-77	7.041	5.035×10^{-9}	94.5	371.4± 4.4
GSA 4A-76	6.532	6.501×10^{-9}	97.5	498.4± 5.6
		Muscovite		
GSA 1-76	8.219[4]	5.208×10^{-9}	97.6	332.8± 3.9

Note: average aliquant weights for determinations were approx. 0.05g.

[1] see figure 2 for locations.

[2] average of 2 determinations.

$^{40}Ar^{*}$: Radiogenic ^{40}Ar.

[3] 1σ errors; $\lambda = 5.543 \times 10^{-10}$/yr; $^{40}K/^{40}K_{total} = 1.167 \times 10^{-4}$ atom/atom.

[4] based on 1 K determination pending duplication.

Results and Conclusions

It is clear from both the regional studies (Morgan, 1972; Espenshade and Clarke, 1976) and from my petrographic study that all of the samples that I analyzed, with the possible exception of GSA 4A-76, contain a mica fabric produced during a Paleozoic metamorphic episode(s). The results of the K-Ar analyses on these new micas are listed in Table I. The dates are interpreted as representing times during post-metamorphic cooling and/or uplift when temperatures dropped below those required for quantitative retention of radiogenic ^{40}Ar in biotite and muscovite. The dates decrease to the east, with the exception of GSA 4A-76 biotite (this anomalous data is discussed in more detail below). This pattern in apparent age, as well as the regular increase in Paleozoic metamorphic grade to the east, is compatible with a cooling model related to an early Paleozoic (Taconic) metamorphic episode.

In a similar terrane in the eastern portion of the Reading Prong, Dallmeyer and Sutter (1976) found that the westernmost appearance of a Paleozoic biotite fabric in a Precambrian basement gneiss yielded a gas retention date of 393 m.y. The westernmost appearance of a Paleozoic horneblende fabric in this same terrane yielded a gas retention date of 472 m.y. Dallmeyer and Sutter thus interpreted the 393 m.y. date for the biotite to represent cooling and/or uplift following a pre-472 m.y. Paleozoic metamorphism (Taconic).

By analogy, it is possible to interpret the 398 m.y. date of the biotite from sample BR 18-77 as a cooling and/or uplift time following an early Paleozoic (Taconic) metamorphism even though no Paleozoic hornblende fabric is present. The pattern of decreasing apparent ages of the micas from west to east (398 m.y. to 333 m.y. for samples BR 18-77, BR 15-77, and GSA 1-76, respectively) with increasing Paleozoic metamorphic grade is also suggestive of all of these dates being times of cooling and/or uplift following a single Paleozoic metamorphic event that must significantly predate the westernmost biotite date of 398 m.y. This interpretation of progressive remetamorphism from west to east is further supported by an 800 m.y. K-Ar date for a biotite taken from a non-retrograded Grenville basement gneiss (Tilton and others, 1960) at Mary's Rock Tunnel in the Shenandoah National Park northeast of Luray, Virginia (figure 2). This is identical to biotite gas retention ages from non-retrograded Grenville gneisses from the Reading Prong reported by Dallmeyer, Sutter and Baker (1975), and interpreted as the time of cooling to the biotite argon retention temperature following the peak of Grenville metamorphism at 1000 to 1100 m.y. ago.

The 498 m.y. date from a biotite separate of sample GSA 4A-76 is anomalously old in light of this previous interpretation. It is possible, as was pointed out in the petrographic description, that more than one generation of biotite is present in this sample. One generation may be relict from weathered basement rocks and either un-affected or only partially reset during Paleozoic metamorphism. Hence a plausible explanation for this anomalous date is that it represents a mixed date of relict and new biotite and has no geologic meaning. Dallmeyer and Sutter (1976) have shown this type if data from partially recrystallized biotites in the eastern Reading Prong.

In conclusion, the limited data I have generated for the micas in the Northern Blue Ridge Province of Virginia are compatible with a model for slow cooling and/or uplift following a single retrogressive metamorphic event. The timing of that event is clearly pre-398 m.y. (the cooling age of the westernmost Paleozoic biotite fabric) and is probably related to the Taconic phase of Paleozoic metamorphism. The polymetamorphic history suggested for this area by earlier workers is not substantiated by this data.

REFERENCES

Allen, R. M., Jr., 1963, Geology and mineral resources of Greene and Madison Counties: Virginia Div. Min. Resources Bull. 78, 102 p.

Bloomer, R. O., and Werner, H. J., 1955, Geology of the Blue Ridge region in central Virginia: Geol. Soc. America Bull., v. 66, p. 579-606.

Brown, W. R., 1958, Geology and mineral resources of the Lynchburg quadrangle, Virginia: Virginia Div. Min. Resources Bull. 74, 99 p.

Cooper, J. A., 1963, The flame photometric potassium determination for K-Ar dating: Geochim. et Cosmochim. Acta, v. 27, p. 525-546.

Dallmeyer, R. D., 1975, $^{40}Ar/^{39}Ar$ age spectra of biotite from Grenville basement gneisses in northwest Georgia: Geol. Soc. America Bull., v. 86, p. 1740-1744.

______ 1975, Incremental $^{40}Ar/^{39}Ar$ ages of biotite and hornblende from retrograde basement gneisses of the southern Blue Ridge: Their bearing on the age of Paleozoic metamorphism: Am. Jour. Sci., v. 275, p. 444-460.

______ 1978, $^{40}Ar/^{39}Ar$ incremental- release ages of hornblende and biotite across the Georgia Inner Piedmont: Their bearing on late Paleozoic- early Mesozoic tectonothermal history: Am. Jour. Sci., v. 278, p. 124-149.

Dallmeyer, R. D., and Sutter, J. F., 1976, $^{40}Ar/^{39}Ar$ incremental-release ages of biotite and hornblende from variably retrograded basement gneisses of the northeasternmost Reading Prong, New York: Their bearing on early Paleozoic metamorphic history: Am. Jour. Sci., v. 276, p. 731-747.

Dallmeyer, R. D., Sutter, J. F., and Baker, D. J., 1975, Incremental $^{40}Ar/^{39}Ar$ ages of biotite and hornblende from the northeastern Reading Prong: Their bearing on late Proterozoic thermal and tectonic history: Geol. Soc. America Bull., v. 86, p. 1435-1443.

Dalrymple, G. B., and Lanphere, M. A., 1969, Potassium- Argon Dating: Principles, Techniques and Applications to Geochronology (Freeman and Company, San Francisco).

Davis, G. L., Tilton, G. R., and Wetherill, G. W., 1962, Mineral ages from the Appalachian province in North Carolina and Tennessee: Jour. Geophysical Res., v. 67, p. 1987-1996.

Espenshade, G. H., 1970, Geology of the northern part of the Blue Ridge anticlinorium, in Fisher, G. W., and others, eds., Studies of Appalachian Geology- Central and Southern: New York Interscience Publishers, p. 199-211.

Espenshade, G. H., and Clarke, J. W., 1976, Geology of the Blue Ridge anticlinorium in northern Virginia, Field Trip Guidebook No. 5: Geol. Soc. America Northeastern- Southeastern Joint Meeting, 26 p.

Furcron, A. S., 1934, Igneous rocks of the Shenandoah National Park area: Jour. Geology, v. 42, p. 400-410.

______ 1939, Geology and mineral resources of the Warrenton

quadrangle, Virginia: Va. Geol. Survey Bull. 54, 94 p.
______ 1969, Late Precambrian and early Paleozoic erosional and depositional sequence of northern and central Virginia: in Precambrian and Paleozoic Appalachian Problems: Georgia Geol. Survey Bull. 80, p. 57-88.
Gathright, T. M., II, and Nystrom, P. G., Jr., 1974, Geology of the Ashby Gap quadrangle, Virginia: Va. Div. Min. Resources Rept. Inv. 36, 55 p.
Hatcher, R. D., Jr., 1972, Developmental model for the Soutern Appalachians: Geol. Soc. America Bull., v. 83, p. 2735-2760.
Jonas, A. I., and Stose, G. W., 1938, Geologic map of Frederick County and adjacent parts of Washington and Carroll Counties: Baltimore, Maryland Geol. Survey, scale 1:62,500.
Long, L. E., Kulp, J. L., and Ecklemann, F. D., 1959, Chronology of major metamorphic events in the southeastern United States: Am. Jour. Sci., v. 257, p. 585-603.
Morgan, B. A., 1972, Metamorphic map of the Appalachians: U.S. Geol. Survey Misc. Geol. Inv. Map, 1-724.
Parker, P. E., 1968, Geological investigations of the Lincoln and Bluemont quadrangles, Virginia: Va. Div. Min. Resources Rept. Inv. 14, 23 p.
Rankin, D. W., Stern, T. W., Reed, J. C., Jr., and Newell, M. F., 1969, Zircon ages of felsic volcanic rocks in the Upper Precambrian of the Blue Ridge, central and southern Appalachian Mountains: Science, v. 166, no. 3906, p. 741-744.
Reed, J. C., Jr., 1955, Catoctin Formation near Luray, Virginia: Geol. Soc. America Bull., v. 66, p. 871-896.
Rodgers, John, 1971, The Taconic Crogeny, Geol. Soc. America Bull., v. 82, p. 1141-1178.
Stose, A. J., and Stose, G. W., 1946, Geology of Carroll and Frederick Counties, in The physical features if Carroll County and Frederick County: Maryland Dept. Geology, Mines, and Water Resources, Carroll and Frederick Counties (Rep.), p. 11-131.
Tilton, G. R., Wetherill, G. W., Davis, G. L., and Bass, M. N., 1960, 1,00-million-year-old minerals from the eastern United States and Canada: Jour. Geophys. Research, v. 65, p. 4173-4179.
Virginia Div. Mineral Resources, 1963, Geologic map of Virginia: Charlottesville, scale 1:500,000.
Virginia Geological Survey, 1928, Geologic map of Virginia: Charlottesville, scale 1-500,000.
Werner, H. J., 1966, Geology of the Vesuvius quadrangle, Virginia: Virginia Div. Mineral Resources Rept. Inv. 7, 53 p.
Wickham, J. S., 1972, Structural history of a portion of the Blue Ridge, northern Virginia: Geol. Soc. America, v. 83, p. 723-760.

ADDITIONAL REFERENCES

Carpenter, R. H., 1970, Metamorphic history of the Blue Ridge province of Tennessee and North Carolina: Geol. Soc. America Bull., v. 81, p. 749-761.

Clark, G. S., and Kulp, J. L., 1968, Isotopic age study of metamorphism and intrusion in western Connecticut and southeastern New York: Am. Jour. Sci., v. 266, p. 865-894.
Hadley, J. B., 1964, Correlation of isotopic ages, crystal heating and sedimentation in the Appalachian region _in_ Lowry, W. D., ed., Tectonics of the Southern Appalachians: Virginia Polytech. Inst., Dept. Geol. Sci. Mem. 1, p. 33-34.